

Figure 5C.4-25. Example of Monthly Proportions of Fall-Run Chinook Salmon Fry/Parr Assumed to be Entering the Plan Area for the Particle Tracking Modeling Nonlinear Regression Analyses. Data are for ESO_ELT Scenario over Calendar Years 1922–1927, With Individual Months Noted as Digits

March–May Differences

In addition to the analysis described above, which focused on a primarily winter migration period representative of fall-run Chinook salmon fry, further analysis was undertaken to illustrate differences between scenarios for migration during March–May. A hypothetical Plan Area entry spread evenly across these three months was represented by applying a weighting of 0.33 to each of the months; all other months received a weighting of zero.

5C.4.3.2.6 Sacramento River Reverse Flows Entering Georgiana Slough

Introduction

Background

Construction and operation of the proposed north Delta intakes as part of *CM1 Water Facilities and Operation* combined with diversion of more water into the Yolo Bypass as part of *CM2 Yolo Bypass Fisheries Enhancement* inevitably would result in less Sacramento River flow below the intakes than would otherwise occur for a given upstream river flow passing Freeport. Much attention has been paid to developing bypass flow criteria—i.e., the required river flow immediately below the intakes—that would limit the potential for greater incidences of Sacramento River flow reversals in the vicinity of Georgiana Slough and the DCC. Depending on the timing and magnitude, flow reversals could affect migrating covered fish species and may increase the likelihood of entry into the interior Delta (i.e., the East Delta subregion in this case), where through-Delta survival probability is considerably lower than that of fish that remain in the mainstem Sacramento River (Perry et al. 2010). The analysis described below assessed the incidence of reverse flows below the

Sacramento River's junction with Georgiana Slough for the EBC2, EBC2_ELT, EBC2_LLT, ESO_ELT, ESO_LLT, HOS_ELT, HOS_LLT, LOS_ELT, and LOS_LLT scenarios using 15-minute outputs from DSM2-HYDRO modeling. The analysis also considered the percentage of total Sacramento River flows approaching the Sacramento River-Georgiana Slough junction that entered Georgiana Slough, as well as the percentage contribution of Sacramento River reverse flows to the Georgiana Slough flow. Finally, the analysis used the results of the DPM (described in detail above) in order to assess the percentage of Chinook salmon smolts migrating down the Sacramento River that entered the interior Delta through Georgiana Slough/DCC.

Summary of Bypass Flow Assumptions

Given the importance of bypass flows, it is useful to review the main elements of the bypass flows that were assumed for modeling purposes, as well as the assumed north Delta intakes pumping regime. Bypass flows were formulated in order to limit upstream tidal transport in the Sacramento River upstream of Sutter Slough and in the Sacramento River downstream of Georgiana Slough. The latter of these is the focus of some of the analyses presented below. The bypass flows are intended to be triggered by pulses of flow that are indicative of major pulses of downstream juvenile fish migration, particularly juvenile Chinook salmon. The main elements of the north Delta diversion bypass flows assumed in the modeling⁷ are as follows, with more detailed provided in Chapter 3, *Conservation Strategy*.

Initial pulses of flow (and fish) are indicated by Sacramento River at Wilkins Slough flow (1) changing by more than 45% over a 5-day period and (2) being greater than 12,000 cfs. During the initial pulse period, north Delta intake diversions may be up to 6% of total Sacramento River flow such that bypass flow never falls below 5,000 cfs, with no more than 300 cfs at any one intake; this is referred to as low-level pumping. Low-level pumping triggered by the initial pulse continues until one of the following occurs: Wilkins Slough flow decreases to flow on first day of the 45% increase; flows decrease for 5 consecutive days; or Sacramento River flows at Wilkins Slough are greater than 20,000 cfs for 10 consecutive days.

Post-pulse operations have three levels. Level I post-pulse operations begin following the initial pulse and last until there have been 15 days of post-pulse bypass flows above 20,000 cfs. In December-April, a sliding scale of bypass flow requirements operates, ranging from requiring 100% of Sacramento River flow to bypass the intakes for river flows of 0–5,000 cfs, up to a bypass flow of 18,400 cfs plus 30% of the amount over 20,000 cfs for river flows over 20,000 cfs. Level II post-pulse operations begin after 15 total days of Level I operations achieving bypass flows above 20,000 cfs. Level II post-pulse operations follow Level I, and also have a sliding scale, ranging from requiring 100% of Sacramento River flow to bypass the intakes for river flows of 0–5,000 cfs, up to 15,900 cfs plus 20% of the amount over 20,000 cfs for river flows over 20,000 cfs. Level III post-pulse operations begin after 30 total days of Level I and Level II operations achieving bypass flows above 20,000 cfs. The sliding scale for Level III operations ranges from requiring 100% of Sacramento River flow to bypass the intakes for river flows of 0–5,000 cfs, up to 13,000 cfs for river flows greater than 20,000 cfs. Criteria for May and June differ from these criteria. More detail is provided in Chapter 3.

⁷ Modeling assumptions may differ from actual operations because of real-time monitoring of fish entry into the Plan Area and other variables.

DSM2 Assumptions for North Delta Intakes Operation

The bypass rules summarized above were simulated in CALSIM using daily Sacramento River flow, which provided the maximum potential diversion that can occur at the north Delta intakes for each day. CALSIM uses the monthly average of this daily potential diversion as one of the constraints in determining the final monthly north Delta diversion. Other goals and constraints may result in CALSIM's monthly diversion amount being substantially less than the potential diversion that CALSIM's daily logic identified. For use in DSM2, the monthly diversion amount was distributed onto the daily pattern of the potential diversion estimated in CALSIM.

Diversion at each intake was subjected to surrogate sweeping velocity criteria for fish protection at intakes. Since DSM2 is a one dimensional model, an average cross-sectional velocity criterion of 0.4 feet/second was used to determine whether or not water could be diverted at an intake. This criterion was based on having a sweeping velocity at least twice that of the approach velocity, the latter having been limited to 0.2 feet/second or less to meet criteria for delta smelt. The sweeping velocity criterion calculated 1,000 feet downstream from each diversion node in DSM2 to represent the minimum sweeping velocity (at downstream end of screen).

The intake operations were also subjected to ramping rates that were required to shut off or start the pumps. The current design allowed ramping up or down the pumps between 0 and 3,000 cfs in less than an hour. These criteria cannot be simulated in CALSIM. They were dynamically simulated using the operating rules feature in DSM2. The north Delta diversion operating rule in DSM2 allows diversion up to the amount specified by CALSIM each day while subjecting each intake to the surrogate sweeping velocity and ramping criteria. The intakes were operated as long as the daily diversion volume specified by CALSIM was not met. Once the specified volume was diverted for the day, the pumps were shut off until the next day.

The volume corresponding to the first 900 cfs of the daily north Delta diversion specified by CALSIM was diverted equally at all three intakes (low level pumping of 300 cfs at each intake). The remaining volume for the day was diverted such that operation of the upstream intakes was prioritized over the downstream intakes. Intake diversions were ramped over an hour to allow smooth transitions and minimize model instabilities when they were turned on and off. The diversion flow at an intake for each time step was estimated assuming that the remaining diversion volume in a day would have to be diverted in one time step at the upstream-most intake first, followed by the next downstream intake, and finally the most downstream intake until the daily specified total was diverted. This basic scheme was adjusted by the surrogate sweeping velocity criteria noted above.

The salient point from these detailed modeling assumptions is that the north Delta intake operations largely were governed by cross-section-averaged sweeping velocity (unadjusted for the velocity at the screen face) downstream of each intake, as opposed to further downstream. There was no explicit consideration of tidal state (e.g., "do not pump during flood tides"), although tidal state would influence the criteria expressed in the modeling assumptions. Multi-dimensional modeling will be necessary to refine estimates of potential diversions.

Analyses of Sacramento River Reverse Flows and Sacramento River Flow Entering Georgiana Slough

The analyses of reverse flows and flow entry into Georgiana Slough were based on 15-minute outputs from the DSM2-HYDRO simulations for each scenario. The results were computed for

16 years, starting from water year 1976 to water year 1991. Flow outputs for Sacramento River downstream of Georgiana Slough (Channel 423 at 1,000 feet or SAC_37), Sacramento River upstream of Georgiana Slough (Channel 422 at 1320 feet or SAC_36), Georgiana Slough (Channel 366 at 0 feet or GEORG_SL), and the net DICU (Delta Island Consumptive Use) flow at node 343 were used.

Monthly Percentage of Sacramento River Reverse Flows Downstream of Georgiana Slough

The frequency of flow reversals in the Sacramento River downstream of Georgiana Slough (SAC_37) was computed by determining the percentage of all the 15-minute flow outputs in each month that had reverse flows, i.e., reverse flows towards the Sacramento River-Georgiana Slough junction. This analysis was conducted for all months and all scenarios.

Percentage of Total Sacramento River Flow Entering Georgiana Slough and Percentage of Reverse Flows

The percentage of Sacramento River flow that approached the Sacramento River-Georgiana Slough junction and entered Georgiana Slough was calculated for each 15-minute output period from DSM2-HYDRO. Three main conditions could occur during each 15-minute time step.

- **Condition 1:** Negative (reversed) Sacramento River flow downstream of Georgiana Slough (SAC_37), i.e., the direction of flow was upstream towards the junction, coupled with positive Sacramento River flow upstream of Georgiana Slough (SAC_36), i.e., the direction of flow was downstream towards the junction. During condition 1, the flow in Georgiana Slough is assumed to be contributed by Sacramento River flows, originating from both upstream and downstream of the junction, as the ratio of the upstream and downstream flow magnitudes, e.g., a reverse Sacramento River flow of 1,000 cfs and a downstream Sacramento River flow of 3,000 cfs would mean that 25% of the water in Georgiana Slough would be from Sacramento River reverse flows and 75% of the water would be from positive Sacramento River flows flowing in a downstream direction.
- **Condition 2:** Negative Sacramento River flow downstream of Georgiana Slough (SAC_37), i.e., the direction of flow was upstream towards the junction, coupled with negative Sacramento River flow upstream of Georgiana Slough (SAC_36), i.e., the direction of flow was upstream away from the junction. During condition 2, the flow entering Georgiana Slough is assumed to be entirely from the reversed Sacramento River flows from downstream of the junction.
- **Condition 3:** Positive flow upstream and downstream of Georgiana Slough. For this condition, only Sacramento River upstream of Georgiana Slough (SAC_36) contributes to Georgiana Slough flow.

For each 15-minute time step, the percentage contribution of upstream and downstream (reverse flows) to Georgiana Slough flows was calculated. The rare occasions in which Georgiana Slough flow was reversing and for which no Sacramento River flow entered Georgiana Slough were excluded from the calculations. The results for all 15-minute time steps were averaged by month. Results are reported below for the monthly average percentage of total Sacramento River flow approaching the Sacramento River-Georgiana Slough junction that entered Georgiana Slough. Also presented in the results is the percentage of reverse flows that entered Georgiana Slough, as this provides an indicator of the risk of advection back upstream into Georgiana Slough for fish that have passed the Sacramento River-Georgiana Slough junction.

The DSM2 simulation period is limited to 16 water years (1976–1991), with a different percentage of water-year types compared to the 82-year CALSIM period (Table 5C.4-25). To assess possible differences in the results based on the percentage of different water-year types, the average percentage of total Sacramento River flow entering Georgiana Slough was calculated for each month in each water-year type for each scenario from the results based on the DSM2 modeling. The monthly averages for each water-year type were then weighted by the percentage of that water year type that is present in the 82-year CALSIM simulation period. This recalculated 82-year grand average for each month was then compared to the grand average from the original DSM2 simulation period.

Table 5C.4-25. Comparison of Number and Percentage of Different Water Year Types from DSM2 and CALSIM Simulation Periods

Water-Year Type	Number of Years		Percentage of Years	
	DSM2	CALSIM	DSM2	CALSIM
Wet	4	26	25%	32%
Above Normal	2	12	13%	15%
Below Normal	1	14	6%	17%
Dry	4	18	25%	22%
Critical	5	12	31%	15%

Assumptions

The main assumptions for the two analyses described above were as follows.

- The 15-minute time step flow data at Sacramento River downstream of Georgiana Slough (SAC_37) is the closest to the junction available from DSM2-HYDRO outputs and represents the flow downstream of the Georgiana Slough junction.
- The 15-minute time step flow data at Sacramento River upstream of Georgiana Slough (SAC_36) is the closest to the junction available from DSM2-HYDRO outputs and represents the flow upstream of the Georgiana Slough junction.
- 15-minute time step flow data at Georgiana Slough (GEORG_SL) is the closest to the junction available from DSM2-HYDRO and represents the flow in Georgiana Slough.
- Flow directions were determined based on the magnitude of the 15-minute instantaneous flow data, where positive flow was assumed to be greater than or equal to 1.0 cfs and negative (reverse) flow was assumed to be less than or equal to -1.0 cfs.
- When upstream and downstream flows are towards the junction (i.e., Condition 1 above), Georgiana Slough flow is assumed to be contributed by both upstream and downstream flows in the ratio of their relative magnitudes. Similarly, DICU is assumed to be contributed by upstream and downstream flows in the same ratio.
- During conditions when flows downstream of the junction are reversing and this is the only flow towards the junction (i.e., Condition 2 above), Georgiana Slough flow is assumed to be contributed entirely by the reversed flow. Similarly DICU is assumed to be contributed entirely by the reversed flow.

- During conditions when flows upstream and downstream of the junction are positive (i.e., Condition 3 above), Georgiana Slough flow is assumed to be contributed entirely by the Sacramento River flow from upstream. Similarly DICU is assumed to be contributed entirely by the Sacramento River flow from upstream.

Percentage of Chinook Salmon Smolts Entering Georgiana Slough/Delta Cross Channel and Steamboat/Sutter Sloughs (Delta Passage Model)

The methods of analysis for reverse flows in the Sacramento River described above provide important context for understanding potential differences in river hydrodynamics between existing biological conditions and BDCP scenarios. A more direct biological linkage is provided by considering the percentage of Chinook salmon smolts from the Sacramento River watershed entering Georgiana Slough and the Delta Cross Channel, using available outputs of the DPM for winter-run, spring-run, fall-run, and late fall-run Chinook salmon. Detailed methods for the DPM are provided in Section 5C.4.3.2.2, *Juvenile Chinook Salmon Smolt through-Delta Survival (Delta Passage Model)*. As discussed therein, Perry (2010) found a linear, nonproportional relationship between flow and smolt entry in Georgiana Slough/Delta Cross Channel. His relationship was applied in the DPM to assess the percentage of downstream-migrating Chinook salmon smolts entering Georgiana Slough/Delta Cross Channel:

$$y = 0.22 + 0.47x;$$

where y is the proportion of fish diverted into Georgiana Slough/Delta Cross Channel and x is the proportion of Sacramento River flow diverted into Geo/DCC (using DSM2-HYDRO flow data for rsac128 and dcc+georg_sl). The proportion was converted to a percentage.

Note that this analysis does not deal directly with potential advection back upstream of Chinook salmon smolts that have passed the Georgiana Slough junction because the DPM does not allow for movement back upstream. Rather, the analysis accounts for the greater percentage of Chinook salmon smolts that would enter Georgiana Slough should reverse flows occur and contribute to greater Georgiana Slough flow relative to Sacramento River flow. The calculations are made on a daily basis and are summed to give the annual percentage of Chinook salmon smolts from each run that entered the interior Delta through Georgiana Slough or the Delta Cross Channel. Note that this is not the same as considering the percentage of smolts from each run that took the interior Delta pathway (as presented in the main DPM results), because the present analysis considers only those approaching the Georgiana Slough/Delta Cross Channel junctions and not the percentage of the total smolts assumed to be entering the Plan Area above Fremont Weir.

In addition to consideration of the percentage of smolts entering the interior Delta through Georgiana Slough/Delta Cross Channel, it is important to consider the percentage of smolts entering Steamboat/Sutter Sloughs, which are important divergences off the mainstem Sacramento River that are downstream of the north Delta intakes and upstream of Georgiana Slough and the Delta Cross Channel. Results from the DPM were used to estimate the percentage of fish entering Steamboat/Sutter Sloughs for each scenario. As described in the DPM methods, the entry of smolts into Steamboat/Sutter Sloughs is assumed to be the same as the flow split, which is derived from DSM2 modeling outputs. An adjusted estimate of the percentage of smolts approaching Steamboat/Sutter Sloughs that would enter Georgiana Slough/Delta Cross Channel, accounting for smolts that would have entered Steamboat/Sutter Sloughs, was made using the formula:

Percentage of fish approaching Sutter/Steamboat Sloughs that enter Georgiana Slough or Delta Cross Channel = $[(1 - \text{proportion entering Steamboat or Sutter Sloughs}) \times [\text{Proportion entering Georgiana Slough or Delta Cross Channel}]] \times 100$.

Note that this formula does not aim to account for any mortality of fish; it simply considers whether any between-scenario differences in the percentage of smolts entering Steamboat/Sutter Sloughs has an effect on the percentage of fish that could enter Georgiana Slough/Delta Cross Channel.

The daily proportion of smolts entering the Plan Area differs for each run of Chinook salmon from the Sacramento River and therefore provides information about potential entry into the interior Delta through Georgiana Slough/Delta Cross Channel over different seasons (Figure 5C.4-26). Winter-run Chinook salmon mostly overlaps winter (December–February) and early spring (March/early April). Spring-run Chinook salmon primarily overlaps spring (March–May). Fall-run Chinook salmon peaks in late spring (early May) and overlaps April–June. Late fall-run Chinook salmon has the broadest entry distribution (summer–winter), with the greatest entry assumed to be in fall (Figure 5C.4-26). Data sources for the derivation of these entry distributions is provided in the DPM methods section.

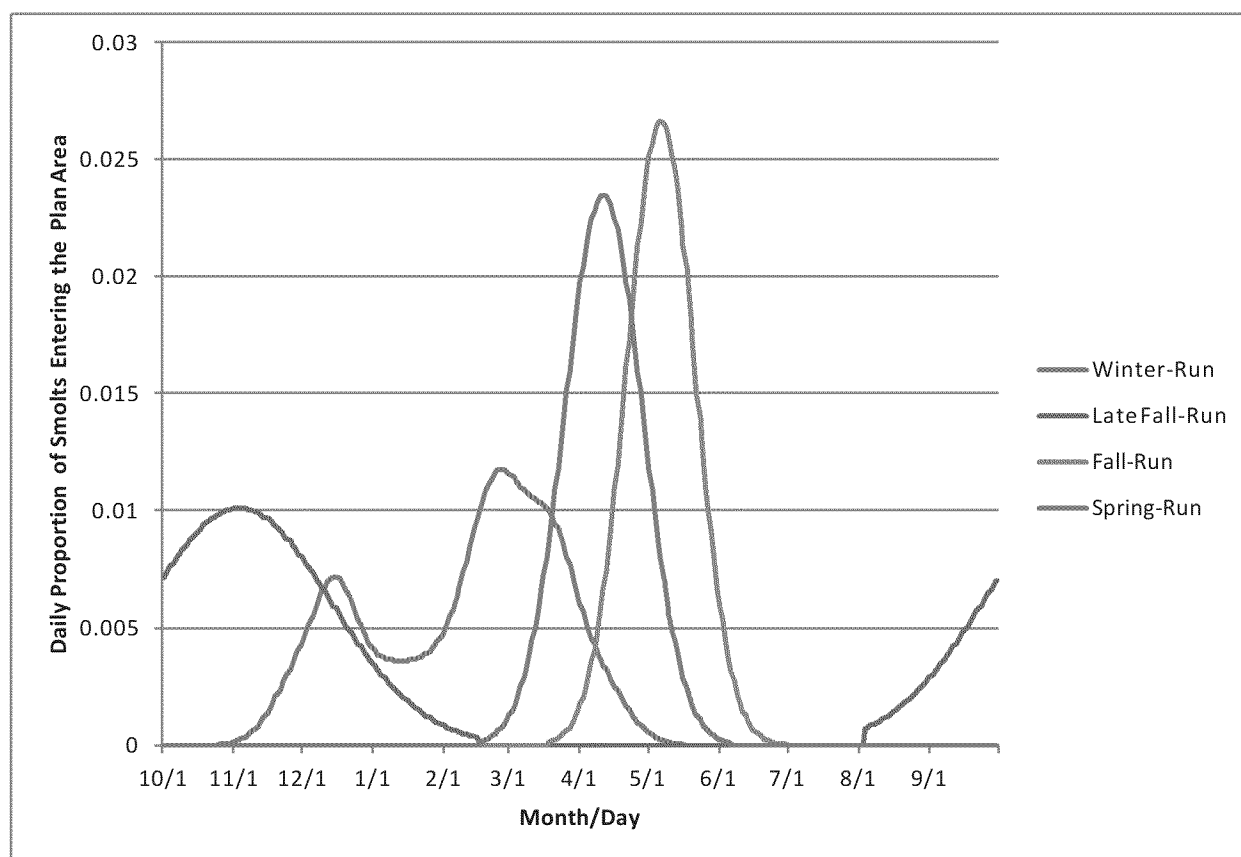


Figure 5C.4-26. Assumed Entry Distribution of Chinook Salmon Smolts from the Sacramento River Watershed into the Plan Area